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EVALUATION OF LOCATION ACCURACY USING P_n AND P_g ARRIVALS

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Seismic event locations obtained by using P_g and P_n arrivals may cause severe errors because the Earth's crust is laterally heterogeneous. Location errors are attributed to the fact that crustal velocities and thicknesses for each source-to-station path are different from those of the standard crustal model used in the location program. To overcome this difficulty, we have installed a number of crustal models in a location program and made it possible for each station to be assigned an appropriate model. Travel times for each

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) phase are computed by using the selected earth model and the specified phase.

The merit of this method is evaluated by relocating 12 explosions in the western United States. When each station model was chosen individually from a number of regional models, location errors were slightly larger than errors using only one (regional) model for all stations. However, errors were reduced when each station was assigned its own model from a set of finely localized crustal models.

Errors were also reduced when the local crustal model appropriate to the source region was used for all stations. This suggests that a crustal model for the source and a separate model for each station would result in even better locations.

P sub g P sub n

The addition of P_g arrivals to the set of P_n arrivals reduced location error by about 30%. However, the difference is not great enough for this small sample but we can be sure that it is significantly different from zero.

EVALUATION OF LOCATION ACCURACY USING

P_n and P_g ARRIVALS

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ABSTRACT

Seismic event locations obtained by using P_g and P_n arrivals may cause severe errors because the Earth's crust is laterally heterogeneous. Location errors are attributed to the fact that crustal velocities and thicknesses for each source-to-station path are different from those of the standard crustal model used in the location program. To overcome this difficulty, we have installed a number of crustal models in a location program and made it possible for each station to be assigned an appropriate model. Travel times for each phase are computed by using the selected earth model and the specified phase.

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1. INTRODUCTION

The accuracy of event location depends strongly upon the variation of crustal structures from the seismic source to each station. We have devised a method to minimize the effect of crustal variations by using various crustal models for each source-to-station path.

Chiburis and Ahner (1970) studied the location accuracy of 28 Nevada Test Site explosions using teleseismic P arrivals. They showed that the location accuracy of these events (depth restrained) averaged about 7.66 kilometers but could be as large as 20 kilometers. They repeated the relocation of those events with station corrections and location errors were reduced to about 2.81 kilometers. However, Chiburis and Ahner cautioned that the set of station corrections for the Nevada Test Site was applicable only to a small region.

Location accuracies resulting from using P arrivals at local stations were investigated by Engdahl and Lee (1976). Three methods were compared in that study. The first method was HYPO71 (Lee and Lahr, 1972), where a uniformly layered crustal model was used. The second method was HYPO74, where different crustal models, as well as station corrections, were used for each individual station. The third method used a complex two-dimensional model to describe crustal variations across the San Andreas fault near Bear Valley. Travel times for each station in the third method were computed by a ray tracing method. Although the third method is the most elaborate one, improvements in location accuracies over the second method appeared to be small. All stations used in their study were within 30 kilometers of the epicenter.

Chiburis, E. F. and R. O. Ahner (1970). A seismic location study of station anomalies, network effects, and regional bias at the Nevada Test Site, Teledyne Geotech, Seismic Data Laboratory Report No. 253, Alexandria, VA.

Engdahl, E. R. and W. H. K. Lee (1976). Relocation of local earthquakes by seismic ray tracing, J. Geophys. Res., 81, 4400-4406.

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2. METHOD OF INVESTIGATION

2.1 The Location Program

The location program used in this project was originally developed by Julian (1974). McCowan (1978) modified it and installed an option to compute travel times for six crustal phases, P_n, P^*, P_g, S_n, S^*, and S_g, from a crustal model (Jeffreys-Bullen model). We modified the program to allow it to use up to fifty crustal velocity models. Furthermore, the program was modified such that each station can use an independent model to compute travel times.

2.2 Crustal Models and Their Usage

Figure 1 shows the boundaries and codes for ten regional crustal models published by Pakiser and Robinson (1966), of which numbers 1 through 7 are used in this investigation. In Figure 2, fifteen more localized crustal models in the southwestern United States (SWUS) are shown. In addition to those models, crustal models for Herrin 68 and Jeffreys-Bullen are also available in the program. Table I is a comparative listing of these models.

The input to the location program must identify the station, signal phase, and the crustal model to be used for this station. To identify the crustal model the analyst must make a preliminary location of the source and, with Figures 1 and 2, decide for each station on the best overall model for the path from the source to the station. Although this scheme provides versatility, it is sometimes difficult to choose a model, as a particular source-to-receiver station path may travel across regions best described by several different models. In such a case the analyst may opt to choose an average model, such as the Herrin model, for this station.

Julian, B. (1973). Extension of standard event location procedures, Seismic Discrimination SATS, Lincoln Laboratory, M.I.T., 30 June 1978, 4-9.

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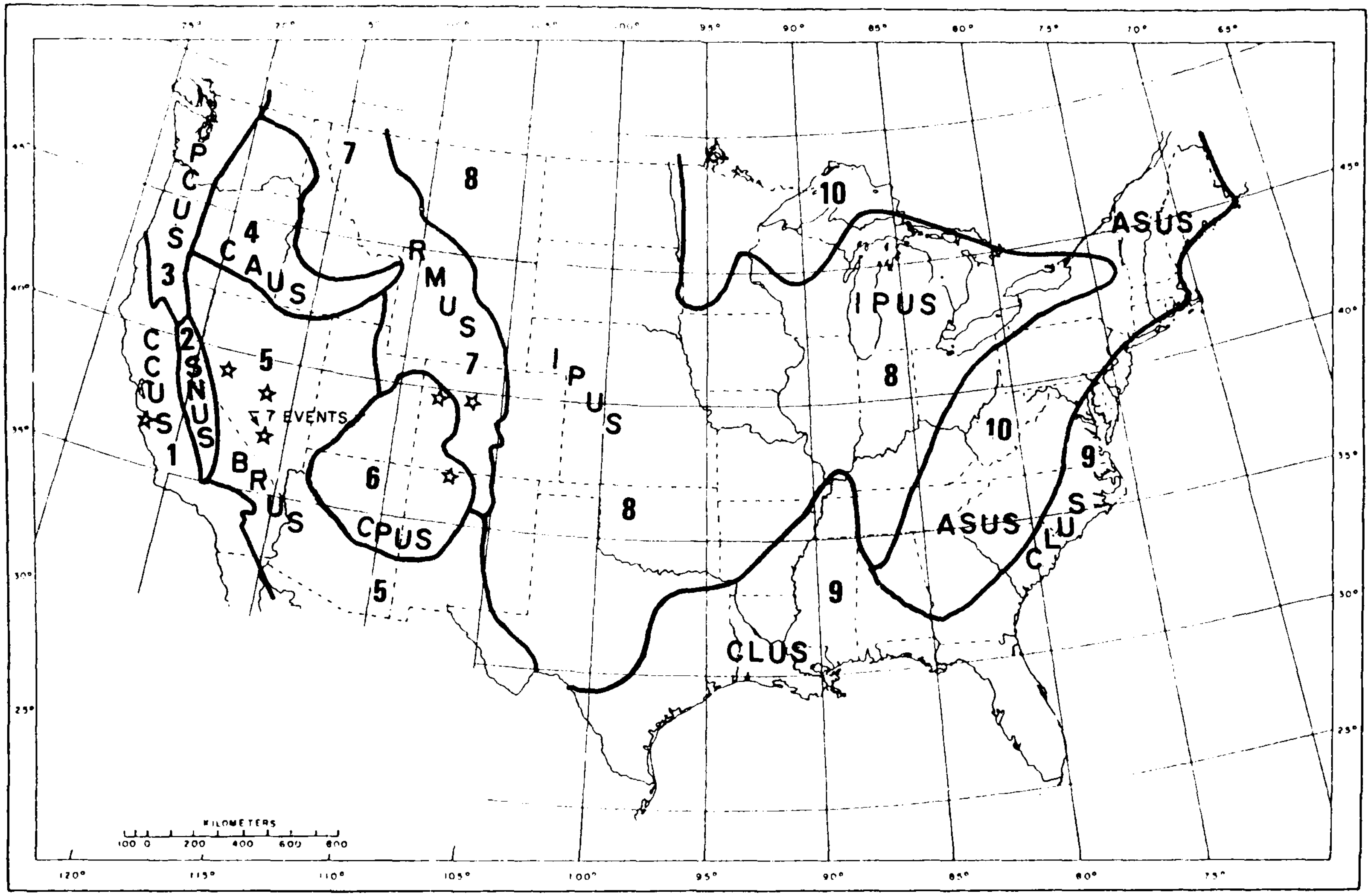

Figure 1. Regions based on seismic properties (after Pakiser and Robinson, 1966).
☆ Event locations.

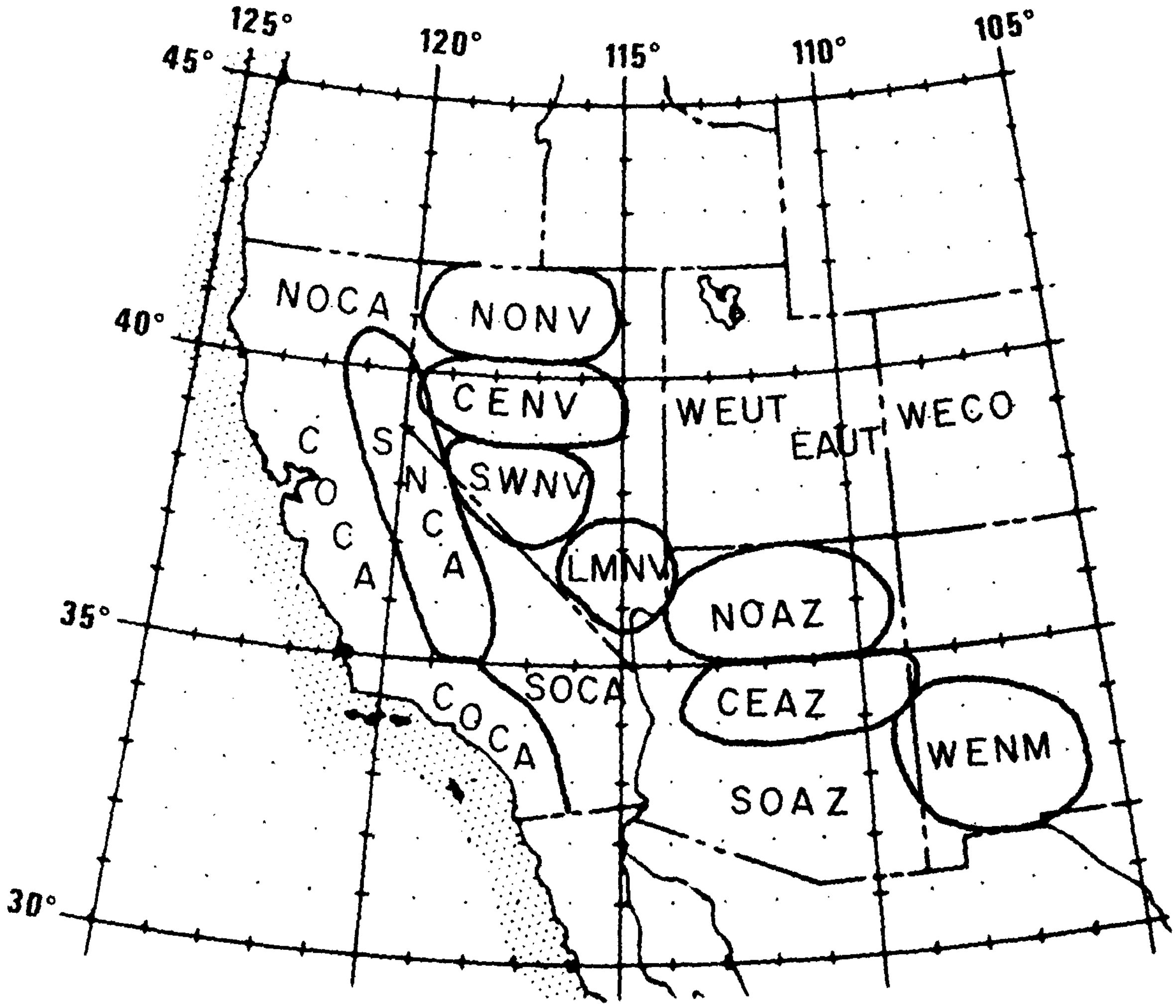

Figure 2. Southwestern United States local crustal models locations.

TABLE I

Comparison of Crustal Structures

Model		1st Layer		2nd Layer		Mantle
Area	Designator	Thickness	Velocity	Thickness	Velocity	Velocity
<u>General:</u>						
Jeffreys-Bullen	J-B	15.00	5.57	18.00	6.50	7.80
Herrin 68	HE	15.00	6.00	25.00	6.75	8.05
<u>Regional:</u>						
Calif. Coast	CCUS	15.00	6.20	5.00	7.00	8.10
Sierra Nevada	SNUS	25.00	6.20	25.00	7.00	7.90
Pac. NW Coast	PCUS	10.00	6.20	25.00	7.00	7.70
Columbia Plat.	CAUS	10.00	6.20	35.00	7.00	7.90
Basin & Range	BRUS	20.00	6.20	10.00	7.00	7.90
Colorado Plat.	CPUS	25.00	6.20	15.00	7.00	7.80
Rocky Mtns.	RMUS	25.00	6.20	15.00	7.00	8.00
<u>Local:</u>						
N. Calif.	NOCA	12.00	5.60	18.00	6.70	8.00
Coast Calif.	COCA	10.00	5.60	10.00	6.70	8.00
Sierra Nevada	SNCA	15.00	6.00	20.00	6.50	7.60
S. Calif.	SOCA	20.00	6.20	10.00	6.90	7.80
N. Nevada	NONV	20.00	6.00	10.00	6.70	7.90
Cent. Nevada	CENV	20.00	6.00	10.00	6.60	7.80
SW Nevada	SWNV	27.00	6.20	9.00	7.10	7.80
Lake Mead Nev.	LMNV	15.00	6.00	15.00	6.50	7.90
W. Utah	WEUT	15.00	5.90	10.00	6.40	7.40
E. Utah	EAUT	27.00	6.20	13.00	6.80	7.80
N. Arizona	NOAZ	26.00	6.00	12.00	6.80	7.80
Cent. Arizona	CEAZ	19.00	6.00	12.00	6.70	7.90
S. Arizona	SOAZ	15.00	6.00	7.00	7.00	7.80
W. Colorado	WECO	9.00	6.00	31.00	6.60	7.80
W. New Mexico	WENM	19.00	6.20	21.00	6.50	7.90

2.3 Data

Twelve nuclear explosions were used as the data base. Of these events seven were at the Nevada Test Site (NTS) and six others were located in Colorado, New Mexico and Nevada.

P_n and P_g arrivals for four events were picked by analysts at the Seismic Data Analysis Center with cross checks to the published shot reports for each event. For the rest of the events, phase arrivals as reported in the shot reports were used. Reading errors of P_n and P_g are greater than errors for teleseismic P. P_n and P_g (especially P_g) signal waveforms are very complex and often emergent. In Table II we list the event parameters, numbers of P_n and P_g arrivals, and the data sources for the events used.

2.4 List of Location Experiments

In the following test categories events were relocated using (a) P_n and P_g phases, (b) P_n only, and (c) P_g only:

1) Local station models;
2) Regional station models;
3) Herrin 68;
4) Epicenter models; and
5) Jeffreys-Bullen.

The Jeffreys-Bullen model was not tested with P_n only, because large residual times were observed using this model. Location errors using P_g only were so large that it was eliminated from further analysis. It was necessary to restrict the event depth to zero in all tests, because the hypocenter depth may go deeper than the crustal thickness during iterations in which case P_n and P_g travel times can not be computed.

TABLE II

List of Events

Name	°LAT	°LON	Date	Origin Time	# of P_n	# of P_g	Data Source	Remarks
PASSAIC	37.1N	116.0W	06 Apr 62	18:00:00.1	4	3	Alex Labs	
DORMOUSE	37.0N	116.0W	05 Apr 62	18:00:00.1	3	4	Alex Labs	
BANDICOOT	37.0N	116.0W	19 Oct 62	18:00:00.1	6	5	Alex Labs	
ROANOKE	37.2N	116.0W	12 Oct 62	15:00:00.1	4	4	Alex Labs	
KLIKITAT	37.2N	116.0W	20 Feb 64	15:30:00.1	13	12	Shot Report	
MERRIMAC	37.1N	116.0W	13 Feb 62	16:00:00.2	8	0	Shot Report	
FAULTLESS	38.6N	116.2W	19 Jan 68	18:15:00.1	5	5	Shot Report	
SHOAL	39.2N	118.4W	26 Oct 63	17:00:00.1	12	1	Shot Report	
ROCKVILLE DAM	39.4N	106.5W	03 Apr 66	16:21:33.6	9	8	Shot Report	
GASBUGGY	36.7N	107.3W	10 Dec 67	19:30:00.1	15	15	Shot Report	
RULISON	39.4N	107.9W	10 Sep 69	21:00:00.1	12	8	Shot Report	
PILE-DRIVER	37.2N	116.0W	02 Jun 66	15:30:00.1	13	12	Shot Report	

3. DISCUSSION

In Table III location errors in latitude and longitude are combined to give errors in kilometers from the true location. The entries in the column giving the best model are determined by consideration of location error, origin time error, and station residuals. Origin time errors in the form of $T_{calc}-T_{true}$ are given in Table IV.

3.1 Location Accuracy with P_n and P_g

Comparing location and origin time errors of runs with $P_n + P_g$ and with P_n only, one notes that the location accuracy with P_s is only about 30% better. The result is not clearly significant and suggests that the addition of P_g to the existing P_n arrivals may not help to improve location.

The best result, an error of 6.31 km, was obtained using crustal epicenter models and $P_n + P_g$. The average origin time error 1.31 seconds is high for this model. The average errors using the Herrin model and P_n arrivals are 8.41 km and 0.53 sec. The average location errors in Table III show that, using proper models the accuracy of event location with P_n and P_g is about 6 to 8 kilometers, or approximately equal to the location accuracies using teleseismic P.

Average location errors using regional models (10 to 11 km) are higher than errors using an epicenter model (6 to 8 km). Location errors using local models (7 to 8 km) are comparable to average errors using the Herrin model (~ 8 km) but with better origin time errors.

These results show that an accurate source model which is correct for portions of all paths, or local station models which correctly handle the upcoming ray at each station, give good results. The implication is that several models are needed for each path to attain excellent results: a source model for the down-going ray, a receiver model for the up-coming ray, and a path model to give the average propagation velocity. However, the present program is designed for only one model per path.

In an attempt to minimize the effect of crustal variations, Herrin and Taggart (1962) computed an average P_n velocity and an average crustal thickness for each individual path. The crustal velocity was assumed fixed through-

TABLE III

Location Errors, km

Name	Various Models For Each Station				One Model For All Stations					Best Model	Remarks * Largest Residuals
	Local Models		Regional Models		Herrin		Epicenter Region Model		J-B		
	$P_n + P_g$	P_n	$P_n + P_g$	P_n	$P_n + P_g$	P_n	$P_n + P_g$	P_n	$P_n + P_g$		
PASSAIC	8.40	9.41	8.40	10.06	4.80	5.85	2.59	3.05	2.36*	HE $P_n + P_g$	
DORMOUSE	8.95	5.21	10.97	8.03	9.18	8.75	5.23	1.39	3.95*	EPI P_n	
BANDICOOT	6.12	6.32	15.91*	16.26	11.91	12.90	10.23	9.89	6.14	Local $P_n + P_g$	
ROANOKE	4.48	5.79	17.51*	19.29	7.55	8.33	6.71	6.92	5.33	Local $P_n + P_g$	
KLIKITAT	6.66	7.10	6.03	8.23	6.85	8.96	4.70	4.08	5.80*	RPI P_n	
MERRIMAC	NA	7.43	NA	6.20	NA	10.28*	NA	8.16	6.60	REG P_n	No P_g Phases
FAULTLESS	4.48	2.26	16.41	21.57	15.09	18.30	14.45	18.41	18.80*	Local P_n	
SHOAL	13.74*	13.63	6.59	6.50	5.90	5.88	3.17	3.20	2.06	EPI $P_n + P_g$	Only 1 P_g Phase
ROCKVILLE DAM	NA	NA	8.44	6.64	5.54	5.08	5.17	6.37	14.62*	EPI $P_n + P_g$	Local models not available for all stations
GASBUGGY	NA	NA	6.79	7.64	3.87	5.20	9.39	13.02	12.63*	HE $P_n + P_g$	"
RULISON	NA	NA	5.99	6.46	5.84	7.32	5.49	6.95	4.11*	EPI $P_n + P_g$	"
PILEDRIVER	NA	NA	10.45	15.84	6.83	4.04	2.33*	21.10	42.24	HE P_n	"
Average Error	7.55	5.14	10.32	11.06	7.67	8.41	6.31	8.54	10.39	EPI $P_n + P_g$	

NA Not applicable because local models not available for all stations

TABLE IV

Origin Time Errors, Sec, ($T_{calc} - T_{true}$)

Name	Various Models For Each Station				One Model For All Stations					Least Residual Model		Remarks
	Local Models		Regional Models		Herrin		Epicenter Region Model		J-B			
	$P_n + P_g$	P_n	$P_n + P_g$	P_n	$P_n + P_g$	P_n	$P_n + P_g$	P_n	$P_n + P_g$			
PASSIAC	- 0.36	- 0.46	0.54	0.44	- 0.16	- 0.16	1.24	1.24	- 0.86	EPI	P_n	
DORMOUSE	- 0.33	- 0.83	0.57	0.17	0.17	- 0.27	1.47	1.37	- 0.93	EPI	$P_n + P_g$	
BANDICOOT	- 0.38	- 0.48	1.42	1.22	0.72	- 0.72	1.82	1.72	- 0.68	Local	$P_n + P_g$	
ROANOKE	- 0.06	- 0.26	2.24	2.14	0.54	0.44	1.84	1.74	- 0.56	HE	$P_n + P_g$	
KLIKITAT	- 0.04	- 0.14	1.36	1.26	0.06	0.16	1.36	1.16	- 1.34	Local	$P_n + P_g$	
MERRIMAC	NA	0.25	NA	0.85	NA	0.25	NA	1.25	- 0.95	EPI	P_n	No P_g Phases
FAULTLESS	0.02	0.02	2.22	2.22	1.50	1.52	2.62	2.52	0.22	Local	P_n	
SHOAL	- 0.40	- 0.50	- 0.10	- 0.10	0.00	0.00	0.90	0.90	- 1.40	EPI	P_n	Only 1 P_g Phase
ROCKVILLE DAM	NA	NA	1.40	1.10	1.40	1.50	1.40	1.10	- 1.40	EPI	P_n	Local models not available for all stations
GASBUGGY	NA	NA	0.50	0.20	0.50	0.60	- 1.60	- 2.10	- 2.70	HE	P_n	"
RULISON	NA	NA	- 0.41	- 0.51	0.49	0.49	0.19	0.01	- 2.71	EPI	P_n	"
PILEDRIVER	NA	NA	0.60	1.80	- 0.30	0.30	0.00	1.21	- 0.80	HE	P_n	"
Average of ABS Errors	0.23	0.37	1.03	1.00	0.53	0.53	1.31	1.36	1.21			

NA Not applicable because local models not available for all stations out the path. We feel that this does not yield a complete solution to the problem because travel time variations due to crustal thickness at source and receiver are much greater than travel time variations due to differences in P_n velocity. For example, assume a particular source-to-receiver path across the adjacent Basin and Range (B & R) and Colorado Plateau (CP) regions where the ray travels through 250 km of B & R and 250 km of CP upper mantle. The difference in P_n velocities between these regions is .1 km/sec, i.e. 7.9 for B & R and 7.8 for CP (Table I); therefore, if one model were used, the error in P_n travel time would be 0.4 second. On the other hand, using the thicknesses of the B & R crust (30 km) and the CP crust (40 km) and an average crustal velocity of 6.6 km/sec for both (Table I), it can be seen that the shortest one-way surface-to-mantle travel time is 1.6 seconds longer for the CP than for the B & R. Thus using one model in this case would mean an error of at least 1.6 seconds in the crustal travel time while the error resulting from the incorrect P_n velocity would be a quarter of that at 0.4 second. This example demonstrates that the effect of the P_n velocity on location accuracy is smaller than the effect of the variations in crustal structures. This also demonstrates why using regional models appropriate to the path but not to the crustal structure under the station may not improve locations.

3.2 Summary and Recommendations for Future Research

The location method used in this study was only marginally successful in improving location accuracy. This is mainly due to the heterogeneity of the crust in the western United States (WUS). The method should produce better results in an area where lateral crustal variations are not as severe as those in the WUS. The reported success in calibrating teleseismic P with the master event method (Chiburis and Ahner, 1970) may not hold with respect to locations with crustal phases because of the stronger effect of lateral heterogeneity on these phases. How accurately the models we used reflect actual crustal conditions is open to question but this is a matter outside the scope of this study.

P_g observations proved not to be as helpful as expected in improving location accuracy perhaps because the onset of this phase is obscured by coda. Consequently, P_n and P_g should not be weighted equally in computing locations but each observation should be weighted as a function of estimated residual variance.

These results show that deviations from the actual structure in crustal models used for event locations contribute significantly to location errors. We therefore recommend that future effort be directed towards improving model structures rather than forcing observed data to fit some given model.

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